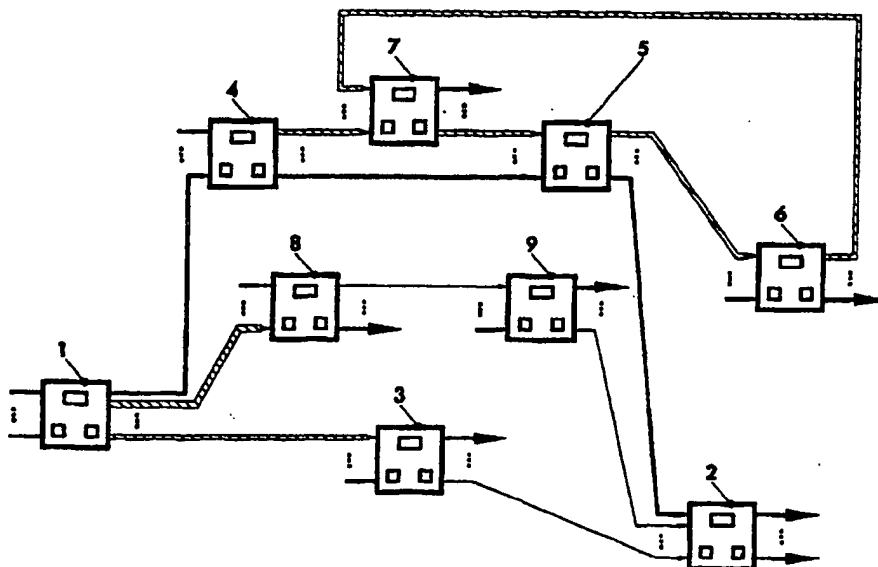




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(54) Title: ROUTING BANDWIDTH-RESERVED CONNECTIONS IN INFORMATION NETWORKS



## (57) Abstract

This invention defines a routing method which allows to determine best paths from link weights in situations where these weights are not additive, but the characteristic of a concatenated path is determined mainly by single "bottleneck" links. To be compatible, the metric must be chosen from a specific set of metrics, called bottleneck metrics in this description. The new widest-path method has some characteristics in common with the known Dijkstra method for additive weights. Implementations in communication networks are disclosed which lead to new nodes, new networks and new network protocols. The widest-path method, however, can solve many other routing problems not necessarily related to electronic communication.

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## DESCRIPTION

5

**Routing Bandwidth-Reserved Connections  
in Information Networks**

10

## TECHNICAL FIELD

The present invention concerns the routing function in information networks, e.g. switch-based computer networks. In such a network it is necessary to determine paths from source nodes to destination nodes. This invention enhances and expands the known Dijkstra routing method to support additional types of service, e.g. reserved bandwidth service, which are not possible with the Dijkstra method. The invented method will also be called "widest-path method" throughout this description. A specific path metric is used, called "bottleneck metric" in the sequel, which was found to be compatible with the algebraic rules that govern the routing method. With this metric, it is possible to reflect realistically enough at least the bandwidth characteristics of the paths, but other characteristics may also be represented. The widest-path method can be used e.g. in connection-oriented networks as Asynchronous Transmission Mode (ATM) or Internet Stream Protocol Version II (ST.II) networks, where the routing decisions are taken at connection setup, but it is not limited thereto. It can be used to precompute paths from any source to any destination and prestore all paths until a respective one is used for a connection request. Such precomputed routing trees are advantageous in source routing methods, where the local source node tree is used to produce a source vector, which describes the path as a sequence of nodes to be covered during packet transmission. The present invention is especially useful in link-state routing mechanisms for networks, but it could be used in the

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1 context of any routing problem for which the widest-path method is  
applicable and for which the bottleneck metric is an appropriate  
representation of the respective path characteristic, even if the context is far  
away from electronic network technology. As examples, passenger or goods  
5 transportation with capacity, financial, legal, or any other bottlenecks, or  
electronic road guide systems shall be mentioned.

### BACKGROUND OF THE INVENTION

10

Link-state algorithms such as Open Shortest Path First (OSPF) are in  
common use for providing the routing function in computer networks  
implementing a connectionless network layer. In such cases, the network  
routing algorithm builds routing tables as a background task. Information  
15 about links is maintained and updated by a topology function replicated in  
all nodes; as a result, every node owns an image of the network, see e.g.  
EP 0 348 327 or EP 0 447 725. This image is used with a shortest-path  
algorithm to compute routes to all destinations. The routing tables,  
produced by the routing algorithm, normally are used to forward individual  
20 packets. With the traditional metrics, optimal paths are "shortest" paths.  
They are obtained by using the conventional Dijkstra method with a path  
"length" given by the sum of the "lengths" of the separate links contributing  
to the path. In such a setting, the "length" of a link is most often not its true  
geometrical length, but can be a value representing any characteristic of  
25 that link. In the following, "weight" will be used as the general term for such  
values. It could represent e.g. monetary costs for the use of that link, and  
one goal of the routing algorithm would be to minimize the cost of the  
network, while maintaining proper connectivity. It could also represent  
delays on that link, the goal would be to minimize the delays in network  
30 data flow. A few examples of metrics in connection with bandwidth or  
occupancy characteristics can be found in EP 0 276 754 and in  
US 4 905 233. In EP 0 276 754, a link weight approximately proportional  
to the occupied capacity is described and used in the Dijkstra method.

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1 A metric that reflects the allocatable capacity available on links is also  
known from US 5 088 032 and US 5 067 127. In US 5 067 127, a  
congestion avoidance control method for communication networks is  
described, which uses a link weight inversely proportional to the available  
5 bandwidth and the path weight is the sum of the link weights. In  
US 5 088 032 a modified Ford path computation algorithm is described.  
There, the weight of a link can be inversely proportional to the available  
bandwidth, and the path weight is determined as the maximum of the  
weights of its links. Whereas it is stated there that other methods of finding  
10 the route with minimum metric may also be used, it is not clear at all that  
any other method is compatible with the metric proposed. A distance vector  
method is described; the Dijkstra method is not mentioned at all. As said  
above, the traditional Dijkstra method uses a path weight, which is  
determined as the sum of the weights of its links, and therefore it is no  
15 substitute for the modified Ford algorithm. Further and in contrast to the  
distance vector method, the widest-path method (as the Dijkstra method)  
builds a complete spanning tree of paths from a source to all destinations  
using a topology database of all nodes, their directly attached links and  
related link weights. This is especially useful in link-state routing  
20 mechanisms and source routing.

In virtual circuit networks, routing is connection-oriented and the routing  
decision is taken at connection setup. If, in addition, connections must have  
guaranteed bandwidth, e.g. for loss-sensitive communication, a virtual  
25 circuit network with bandwidth reservation is necessary. Examples are  
networks of ST-II routers and ATM networks. There, all packets or cells  
belonging to a connection follow the same path. In such cases, the routing  
algorithm applies to the routing of connection setup messages, this is also  
referred to "call routing".

30

It is a general object of this invention to avoid the different drawbacks of the  
prior art and to extend and modify the Dijkstra routing method in a way  
which allows to determine from the weights of the bottleneck link or links of

1 each path the "best" path, which is defined to include the "widest"  
bottleneck, that is the link with the most favorable (smallest or biggest)  
weight. It is another object to provide a link-state routing method,  
especially for virtual circuit networks, with guaranteed bandwidth or  
5 bandwidth reservation or with other characteristics which necessitate a  
bottleneck metric. A further object is to improve a network node by  
implementing in it a routing function enhancement comprising the  
widest-path method; improvements to the topology function are proposed to  
include in its update method a modified dampening method and/or a  
10 bandwidth encoding method to enable consideration of dynamically varying  
available bandwidths. Further disclosed is a network comprising improved  
nodes which may be mixed with normal nodes not supporting the devised  
enhancement.

15

#### SUMMARY OF THE INVENTION

The above objects are accomplished by enhancing and extending the  
Dijkstra routing method by applying an appropriate metric to determine link  
20 weights and path weights. An appropriate metric must reflect at least  
approximately the characteristics of the paths to be taken into account in the  
routing method and it must be compatible with this method. As was found,  
the bottleneck metrics comply with these constraints. They include metrics  
which are defined so that the weight of a path is given by the maximum of  
25 the weights of its links, and a link or path with smaller weight is the better  
link or path, respectively. In this case, with the widest-path method, the best  
paths are still paths with minimal weight in this case, as with the Dijkstra  
method. A formal description of such an example of the method in  
algorithm form is given in the appendix. There, a case is selected where the  
30 operation of link weight summation in the Dijkstra method is always  
replaced by a maximum operation which has the maximum of the link  
weights as its result. This definition means that the weight of a  
concatenated path is now the maximum of the weights of its links instead of

1 the sum. It is possible to formally proof that the algebraic rules which  
govern the method hold for both operations. The beauty of the widest-path  
method is that it is easy to implement and can replace the Dijkstra method,  
where appropriate, without complications. Clearly, the bottleneck metrics  
5 include other metrics, too. As examples, the minimum (or another  
extremum) of the component link weights (or their absolute values) can be  
used to determine the path weight directly or after further calculation,  
provided that the calculation applied is a non-decreasing function. The  
median of component link weights or the component link weight closest to a  
10 predetermined target value can be used, if these reflect the path  
characteristic to be described. As a rule, an operation on the weights of the  
component links of a path is applied to select at least one link (the  
"bottleneck link") of the path, and the path's weight is then determined from  
the weights of its bottleneck links.

15  
In the context of communication network routing, the metric reflects the  
allocatable capacity available on links and the widest-path method is used  
for the computation of the path with the highest allocatable capacity. In  
link-state routing, network nodes share link state information that reflects  
20 the available bandwidth on each of the links of the network. This is  
performed by encoding the available capacities as link weights and using a  
known distribution mechanism, called "topology function", for transmission.  
As the available capacity varies very dynamically, it is necessary to prevent  
excessive amounts of link state updates. This is known as "dampening" and  
25 an appropriate dampening method is described. The routing function can  
be applied to connection setup requests instead of individual packets. The  
widest-path method computes paths from any source to any destination,  
using the information obtained from the topology function. The paths can be  
stored and used to route connection requests as they arrive. One feature of  
30 the "widest-path" definition is that either a connection setup can be routed  
along a widest path, no matter how much bandwidth it requests, or it cannot  
be routed at all in the network. In other words, the method guarantees that  
the connection will find a path with sufficient bandwidth, assuming there

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1 exists such capacity in the network at all, and assuming the information  
provided by the topology function is up-to-date. This also means that one  
single computation can serve all possible bandwidth requests. One benefit  
of the widest-path method is that it is compatible with and allows the reuse  
5 of the well-tested routing function code. An additional benefit is that the  
routes produced by the method are computed and stored in advance of  
connection requests, thus supporting fast connection setup. In addition, the  
method can be used in conjunction with a routing protocol such as OSPF to  
work with standard network nodes that do not support the widest-path  
10 method. This way, mixed networks including enhanced and standard  
network nodes become possible. The method does not limit the number of  
hops. This is insignificant in many applications, but the limitation can be  
changed if necessary.

15

#### BRIEF DESCRIPTION OF THE DRAWINGS

An embodiment of the invention is described in detail below with reference  
to the drawings. To show more clearly the general inventive concept, a  
20 specific implementation in a communication network node is assumed.  
Additional inventive features in this context are also disclosed.

FIG. 1A illustrates schematically the widest-path method according to  
the invention. A typical routing problem with a bandwidth  
25 bottleneck situation in a network domain is assumed to explain  
this method in contrast to the state of the art.

FIG. 1B shows in more detail a node of the domain of Figure 1A and  
the related information flow.

30

FIG. 2 depicts a mixed network of widest-path areas and standard  
areas.



1     **FIG. 3**         shows an exponential bandwidth encoding format for link-state  
                    update information.

**FIG. 4**         illustrates call routing and the related information flow.

5

### DETAILED DESCRIPTION OF AN EMBODIMENT ACCORDING TO THE INVENTION

10    A path is the concatenation of links, also called "component links" of the  
      path, between network nodes. The width  $C_{path}$  of a path is defined as the  
      minimum of the available capacity on each of the component links. The  
      available capacity is the bandwidth, in bits per second, that can be allocated  
      to user connections. Therefore, the capacity bottleneck link determines what  
15    capacity is available on a path. A "widest path" is a path that, among all  
      paths between one source and one destination, has the largest width.

      Figure 1 illustrates a widest-path example in a domain including nodes 1 to  
      7 of an arbitrarily meshed network. Links of different available bandwidths  
20    are shown and the respective bandwidth is depicted by the width of the link  
      connecting line. As is shown, a widest path from node 1 to 2 is the path  
      1-4-5-2, with an assumed width of say 40 Mb/s, determined by link 5-2.  
      Whereas link 1-3 (100 Mb/s) is broader than 1-4 (60 Mb/s), path 1-3-2 is  
      narrower than 1-4-5-2. It has a width of only 20 Mb/s, say, due to the  
25    bottleneck link 3-2. Weights are applied to the links in such a way that a link  
      with smaller weight is not narrower than a link with bigger weight. Then, the  
      widest link is a link with smallest weight and the narrowest link is a link with  
      biggest weight. As an example, the weight  $W_{link}$  of a link is defined as

30     $W_{link} = C_{max} - C_{link},$

      where  $C_{max}$  is a constant assumed to be larger than any link capacity (say  
       $C_{max} = 16 \text{ Gb/s}$ ).  $C_{link}$  is the available capacity, or bandwidth of the link.

1 Clearly, the conventional Dijkstra method would prefer path 1-3-2 of weight  
D132 =  $W_{13} + W_{32} = 2C_{\max} - 120$  Mb/s, and also path 1-8-9-2 (150 Mb/s,  
20 Mb/s, 20 Mb/s) of weight D1892 =  $3C_{\max} - 190$  Mb/s, over the true  
widest path 1-4-5-2 of weight D1452 =  $3C_{\max} - 150$  Mb/s (assume 50 Mb/s  
5 for link 4-5). In the widest-path metric, the weight of a path is defined as the  
maximum of the weights of its component links, that is, it is determined by  
its narrowest link. Thus,

$$\begin{aligned} W_{\text{path}} &= \text{Max}(W_{\text{component-link}}) = C_{\max} - \text{Min}(C_{\text{component-link}}) \\ 10 \quad &= C_{\max} - C_{\text{path}}. \end{aligned}$$

With this bottleneck-type metric, in this context also called widest-path  
metric, the widest path is again a path with smallest weight, as with the  
Dijkstra method, but the widest-path method prefers path 1-4-5-2 of weight  
15  $W_{1452} = C_{\max} - 40$  Mb/s over paths 1-3-2 and 1-8-9-2 of weights  $W_{132} =$   
 $C_{\max} - 20$  Mb/s =  $W_{1892}$ .

The reason for defining the weights as complements to  $C_{\max}$  is the  
compatibility with the shortest path method used in network domains that do  
20 not use the widest-path method. As stated in Summary of the Invention,  
above, other link weights can be used for a bottleneck metric, e.g. to reflect  
other characteristics of the links or to ease calculations or encoding of  
link-state information. Examples are  $W_{\text{link}} = K/C_{\text{link}}$ , see Background of the  
Invention, above, and the exponential encoding described below.

25

By nature, the widest-path method builds a tree of paths (as the Dijkstra  
method), so the resulting graph is always loop-free. There may exist paths,  
e.g. 1-4-5-6-7-5-2 that are optimal in the sense of the widest-path metric, but  
contain loops. Such paths are excluded automatically by the widest-path  
30 method. The quality of the paths can be further improved by adding to the  
method the constraint that, among all widest paths, only the ones with the  
least number of hops or, more precisely, number of link state  
advertisements used are retained. This defines a precedence of

1 equal-weight routes. In the example, path 1-4-5-2 precedes path 1-4-7-5-2 of  
equal weight which is determined by bottleneck link 5-2 in both cases.

To make the method work in a link-state, connection-oriented routing  
5 environment, the nodes of the network need new capabilities. Figure 1B  
shows a network node according to the invention including a known  
topology function 10. A widest-path generator 12 is connected to the  
topology function 10. Upon connection requests 13 from a network user, the  
widest path is assigned to route the connection. Further, link-state update  
10 information 14 is exchanged between network nodes to keep the topology  
function up to date. A bandwidth information update module 11 is connected  
to the topology function to include bandwidth information in the link-state  
update information 14 for variable available link capacity. Module 11 is  
15 comprising an encoder to format a bandwidth information to be sent out by  
the node, a receiver for receiving and, if necessary, decoding bandwidth  
information of other nodes, and a dampening mechanism avoiding  
immediate updating reaction to small bandwidth changes.

Module 11 encodes the available bandwidth  $C_{link}$  on a link as a 16-bit  
20 weight, see Figure 3. This format is used for compatibility reason with  
existing link-state algorithms. An exponential notation is used in order to  
cover a range from 1 bit/s to  $C_{max} = 16 \text{ Gb/s}$ . The encoding uses 8 as the  
exponentiation basis, 3 bits of exponent 21 starting from the most significant  
bit 23, and 13 bits of mantissa 22, ending with the least significant bit 24.  
25 There may be several ways to encode a specific capacity  $C_{link}$ . Among all  
encodings (exp, mant) for one capacity  $C_{link}$ , only the one with the smallest  
exponent is declared valid. This rule allows to put away with decoding  
capacities before manipulating them, because the usual comparisons on  
"long integers" apply. Namely, if  $c, c'$  are the 16-bit encodings of link  
30 capacities  $C, C'$ , then

$$C < C' \iff c < c' \iff W > W'.$$

1 Changing available bandwidth of a link with immediate bandwidth updating  
of all nodes, which is similar to changing its weight, can lead to disastrous  
scenarios, such as storms of link-state updates propagating through the  
network during a period of very frequent connection setups. This can lead to  
5 congestion, excess transient loops and similar problems often encountered  
in situations of overcorrections. To avoid this, a dampening method was  
defined which only invokes link-state updates for a link when a significant  
change appears, e.g. when an amount of its bandwidth has been reserved  
which is larger than a certain dampening threshold. For example, five  
10 connections for a fraction of Mbits/s each on a link of several Gbits/s  
occurring in a second would lead to five times distributing a change of not  
even 0.1% of the link's capacity, and probably to recomputation of the  
topology through all nodes. This is clearly unacceptable. The dampening  
method is based on the fraction of link bandwidth reserved. To achieve this  
15 goal, a threshold MaxDBandwidth must be provided that during the change  
of the dynamic link weight decides whether the new link advertisement  
should be started or not. Because of this requirement, every link must,  
beside the bandwidth weight field, contain a cumulated, not flushed, change  
in weight called delta-bandwidth. Every connection setup or release  
20 changes the delta-bandwidth and checks whether it exceeds the threshold. If  
it does, new topology update is propagated. One problem still remains,  
namely the "opaqueness" of the delta-bandwidth cost to all nodes. When  
the bandwidth of a link has been changed and "absorbed" by the  
delta-bandwidth field, it can potentially not be advertised for a long period  
25 of time. A possible routing mismatch during this period of time could  
happen, although this is rather unlikely, because the threshold should be so  
small that not distributing the delta should be negligible for routing.  
Nevertheless, a periodic timer for each node link is introduced, which is  
started whenever delta-bandwidth is changed from 0 to a value not equal to  
30 0 and reset each time delta-bandwidth is set to 0. When the timer expires, it  
flushes delta-bandwidth if necessary. The dampening constant of 5% of the  
available link bandwidth is based on the behavior of a typical scenario  
assumed with either uniform or exponential size distribution of the requests

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1 arriving at a constant rate with a maximum size of 10% of the link  
bandwidth.

Most of the up-to-date link-state routing protocols offer the capability of  
5 dividing the routing domain into subdomains. A topology information is  
summarized at the boundaries of the subdomains and only the summary is  
distributed. Certain constraints have nevertheless to be met to guarantee  
the non-ambiguity of the distributed information. The method of widest-path  
areas is proposed which allows to intermix subdomains understanding  
10 widest-path and standard metrics with those only understanding standard  
metrics. An example of such a mixed network is depicted in Figure 2. Three  
widest-path areas 16,17,18 of different topologies are shown imbedded in a  
network with areas 19,20 of standard nodes. On boundaries 15 of two  
subdomains with different characteristics, the unsupported metrics are  
simply dropped. This allows a gradual introduction of the widest-path  
method in routing domains. Here, the necessary changes for a OSPF  
standard routing protocol are described to get so called WET-OSPF, but  
other mixed networks are possible. WET denotes the three option bit names  
W, E, and T, of which only W is related to the widest-path area method. E  
20 and T are not relevant here.

In this context, network nodes are called "routers". Widest-path areas  
consist only of routers supporting the widest-path method. This is  
determined by a similar mechanism as the one used to have all routers in a  
25 stub area agree about the stub property. A new option bit is introduced,  
called W-bit. Routers of a widest-path area set this bit sending so-called  
hello-packets on area interfaces and refuse to build adjacency to routers in  
the area that do not have this bit set. Interfaces of widest-path routers  
connecting to a standard area will not have this bit set in the hello-packets,  
30 but only in the options field of the link advertisement for summary links, so  
that distribution of bandwidth metrics over the border of two widest-path  
areas will work. Moreover, a new time constant WET-MinLSInterval is  
introduced, beside the MinLSInterval of OSPF. The MinLSInterval is used

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1 on the area interfaces of a router, the WET-MinLSInterval on the WET-area  
interfaces. Inside the area, the router link advertisement is distributed using  
WET-MinLSInterval. The method has the advantage that these  
advertisements will not be distributed into the next area, only summary link  
5 advertisements will. The summary link advertisements are installed in  
intervals equal to or larger than MinLSInterval. Nevertheless, this does not  
influence the router link advertisement, which can be installed as fast as  
WET-MinLSInterval allows, because all routers inside the area are using this  
interval on such interfaces.

10

As a result of the widest-path method, every node in the network produces a  
local routing tree. This information can be used for call routing in a number  
of ways. One particularly attractive method is to use source routing, as  
mentioned above. An example of a call routing method used for setting up  
15 calls is illustrated in Figure 4. A connection setup request 13 is sent from a  
source 25 to route a connection to destination 26. The local, pre-computed  
routing tree from a widest-path generator 12 at the source node 1 is used to  
produce a source vector, describing the path as a sequence of nodes 1,4,5  
to be visited. Intermediate nodes 4,5 do not use the local routing tree, but  
20 instead consult the routing vector carried by every packet or connection  
setup message 13. This guarantees loop free routing of the call setup, since  
the widest-path method according to the invention always builds a loop free  
graph. Link-state update information 14 is exchanged between the nodes  
1,4,5 as necessary.

25

The method presented here provides a means for computing paths. As  
should be clear from the foregoing detailed description, a routing method is  
described, which allows to determine the best path in a network from link  
weights in situations where these weights are not additive, but the weight of  
30 a path is defined by its bottleneck link. To be compatible with the method,  
the metric must be chosen from a specific set of metrics, called bottleneck  
metrics in this description. The new widest-path method has some  
characteristics of the well known Dijkstra method for additive weights.

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1 Implementations in communication networks are described, which lead to  
new nodes, networks and related protocols, but the widest-path method can  
be used in many other routing problems, examples are given above. It can  
easily be seen that the widest-path method of the embodiment does not  
5 minimize the number of hops, only the availability of bandwidth is  
considered. The method as described is thus not directly adapted for wide  
area networks where bandwidth optimization is essential, but with some  
modifications it might be used for these applications, too. In contrast, it is  
attractive for local area networks due to its aforementioned benefits of  
10 compatibility with the Dijkstra method and as extension of OSPF, and  
because of its path precomputation capability. The method can be extended  
in many ways, depending on the application, without departing from the  
general inventive concept; it is envisioned to account for path quality, path  
security, or passenger comfort, to name a few applications. Various call  
15 setup schemes are possible, including multiparty calls; also, numerous  
modifications depending on intended network environment and types of  
nodes can be made in accordance with the general concept of the invention.  
All these different embodiments can be implemented by someone skilled in  
the art and thus fall within the scope of this invention.

20

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## APPENDIX

## 1. Formalism and Assumptions

- uses  $\exists$  operator to check for existence
- $Head()$ ,  $Tail()$  return head or tail of a list. 0 if empty
- $Head + (e, q)$ ,  $Tail + (e, q)$  adds a element  $e$  to list  $q$  only if it is not yet in the list
- $Head - (q)$ ,  $Tail - (q)$  remove head. tail of list and returns removed value or 0 if list empty
- $Insert(e, k, q)$  inserts element  $e$  into list  $q$  at position  $k$
- $MAX$  gives the maximum of its arguments
- $n$  gives the number of elements in a list
- $[x]$  is the element at place  $x$  in a array or list or set
- node 1 is the source
- $R$  is number of nodes
- $\{ \}$  denotes a empty set or list



- 15 -

## 2. Algorithm

```

Node : ARRAY[1..R] OF
    SET Links OF STRUCTURE Link
    BEGIN
        INTEGER destination;
        INTEGER cost;
    END; /* topology database */
Spf  : SET OF INTEGER; /* set of nodes on spf tree */
Route: ARRAY[1..R] OF
    LIST Hops OF STRUCTURE Element
    BEGIN
        INTEGER node;
        INTEGER link_ndx;
    END;
    /* set of node and link indices on the route from source to destination */
Cand : LIST OF INTEGER;
    /* indices of candidates to test next step sorted on distance */

INTEGER FUNCTION Length ( rout: LIST OF STRUCTURE Element );
/* computes length of a route given as list of links */
BEGIN
    RETURN MAXj:=1j<#rout Node[rout.Element[j].node].Link[rout.Element[j].
    link_ndx].cost;
END; /* of function */

INTEGER c;
INTEGER i,j,k,dst,dist;

/* Topology Database already installed */
Route [ 1..R ] := { };
Cand      := { };
SPF       := { };
c         := 1; /* index of the computed node, 1 is source */

```

## 2. Algorithm (continued)

```

WHILE  $c \neq 0$  DO
  FOR  $i:=1$  TO #Node[c].Links /* number of this node's links */
     $dst := \text{Node}[\text{Node}[c].\text{Links}[i].\text{destination}]$ ;
     $Head+(c, \text{Spf})$ ;
    IF ( $\exists x \mid \text{Node}[dst].\text{Links}[x].\text{destination} = c$ ) AND  $dst \notin \text{SPF}$ 
      /* checks whether a back link exists and destination not
      already computed on tree ?? */
       $dist := \text{MAX} ( \text{Node}[c].\text{Links}[i].\text{cost}, \text{Length}(\text{Route}[c]) )$ ;
      IF ( $dist < \text{Length}(\text{Route}[dst])$ ) OR  $\text{Length}(\text{Route}[dst])=0$ )
         $\text{Route}[dst] := \text{Route}[c]$ ;
         $Tail+(\text{Element}(c, i), \text{Route}[dst])$ ;
         $k:=1$ ;
        WHILE  $k < \#Cand$  AND  $\text{Length}(\text{Route}[k]) < dist$ 
           $k:=k+1$ ;
        END;
         $\text{Insert}(dst, k, Cand)$  ; /* insert sorted on candidate list */
      END;
    END;
  END;
   $c = Head-(Cand)$ ;
END;

```

## 1 CLAIMS

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1. Method for determining the best path of a plurality of paths from a source to a destination in or through a network of nodes and links between the nodes, wherein
    - each link has assigned a link weight reflecting a selected link characteristic,
    - the path weight of a, preferably each, concatenated path is determined by the link weights of its components,
    - the path weights of said plurality of paths determine said best path,
    - a best path tree is constructed from said source to at least one destination using a topology database containing the nodes, their attached links, and the related link weights for each concatenated path taken into account,
    - a subset is selected containing at least one link from the set of component links of said path by applying an operation on the link weights of said path's component links, and
    - a path weight is determined of said path from the link weights of its selected links.
  2. The method according to claim 1, wherein an extremum of the component link weights is used for the subset selecting step.
  3. The method according to claim 1, wherein the maximum of the component link weights defines the weight of a concatenated path.
  4. The method according to claim 1, wherein, in a digital communication network, the link weights reflect available bandwidth on the links, all link weights are positive, and smaller link weight means broader bandwidth.
  5. The method according to one or more of claims 1 to 3, wherein the link weights reflect transport capacity, in particular in a road network or for goods or passengers.

- 1 6. Routing device (10,12), for a network of nodes (1-9) and links between  
the nodes, comprising
- a memory storing information about link states including weights  
reflecting a characteristic of the links, and
  - 5 — a best path generator determining the weight of a path from the  
link weights of its component links, and determining the best path  
using the path weights of a plurality of paths from a source to a  
destination in or through the network,  
wherein
  - 10 — said memory contains the nodes, their attached links, and the  
related link weights,
  - said best path generator (12) comprises selection means for  
selecting a subset of at least one link from the set of component  
links of a path by applying an operation on the weights of the  
15 path's component links, and weighting means for determining the  
weight of a concatenated path from the link weights of its selected  
links.
- 20 7. The routing device according to claim 6, wherein the link weights reflect  
available bandwidths on the links in a digital communication network.
8. The routing device according to claim 7 for a network with dynamically  
changing available bandwidth, comprising a bandwidth information  
update module (11), including
- 25 — an encoder which exponentially encodes the available bandwidth  
on a link, and
  - a dampening mechanism for avoiding immediate updating reaction  
to small bandwidth changes.
- 30 9. Network node (1-9), comprising a routing device (10,12) according to  
one or more of the claims 6 to 8.

- 1      10. Network, in particular digital communication network, comprising at  
least one routing device (10,12) according to one or more of the claims  
6 to 8.
- 5      11. Mixed network, comprising at least one node according to claim 9 and  
one or more other nodes, and applying a routing protocol using the  
method according to one or more of the claims 1 to 4 for subdomains  
(15-20) of said mixed network.
- 10     12. Use of a method according to one or more of claims 1 to 4 or of a  
routing device according to one or more of claims 6 to 8, to enable  
reserved-bandwidth services in a virtual circuit network.
- 15     13. Use of a method according to one or more of claims 1 to 4 in a  
link-state routing protocol of or in a network using source routing.

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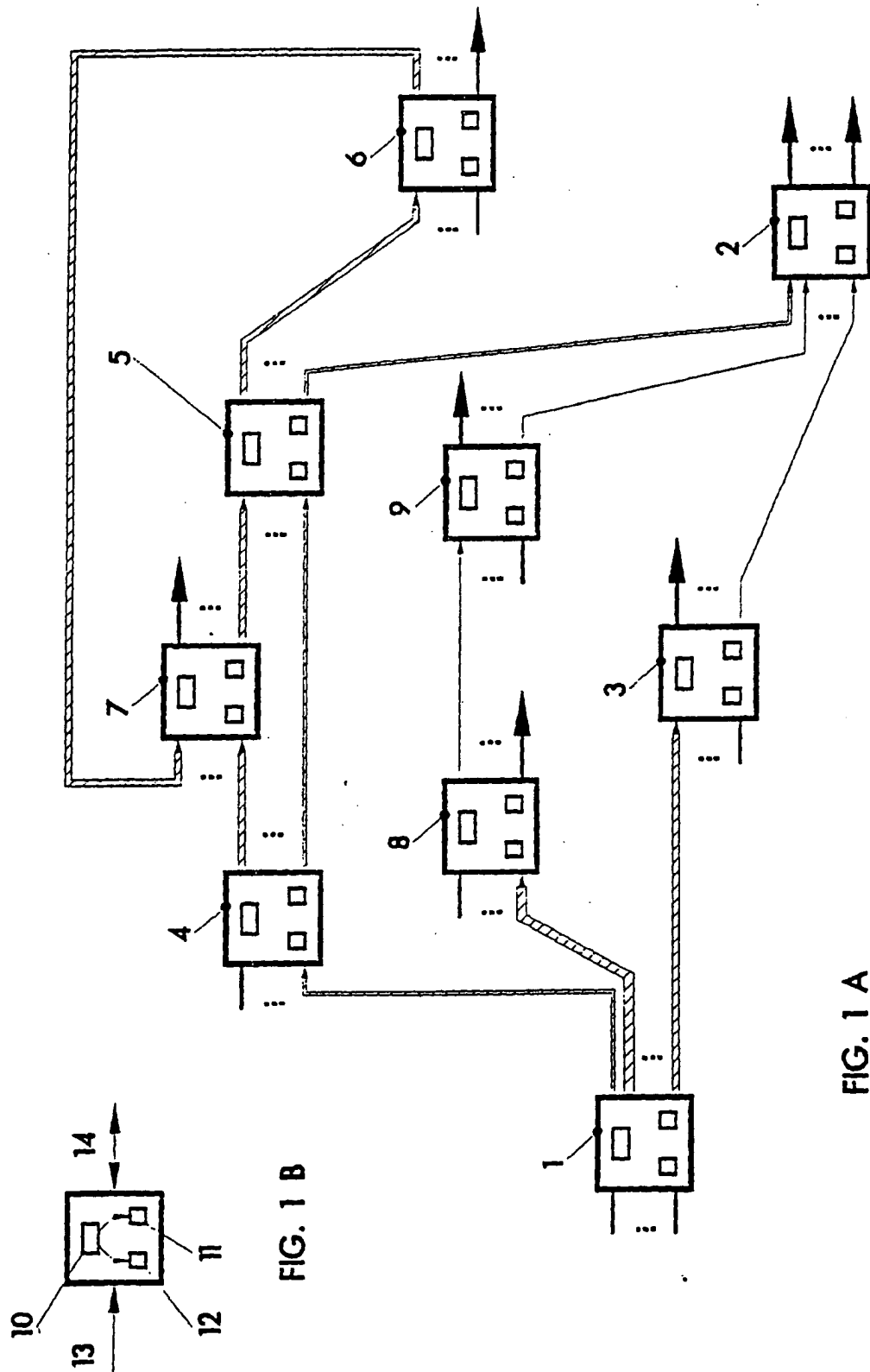


FIG. 1 A

FIG. 1 B

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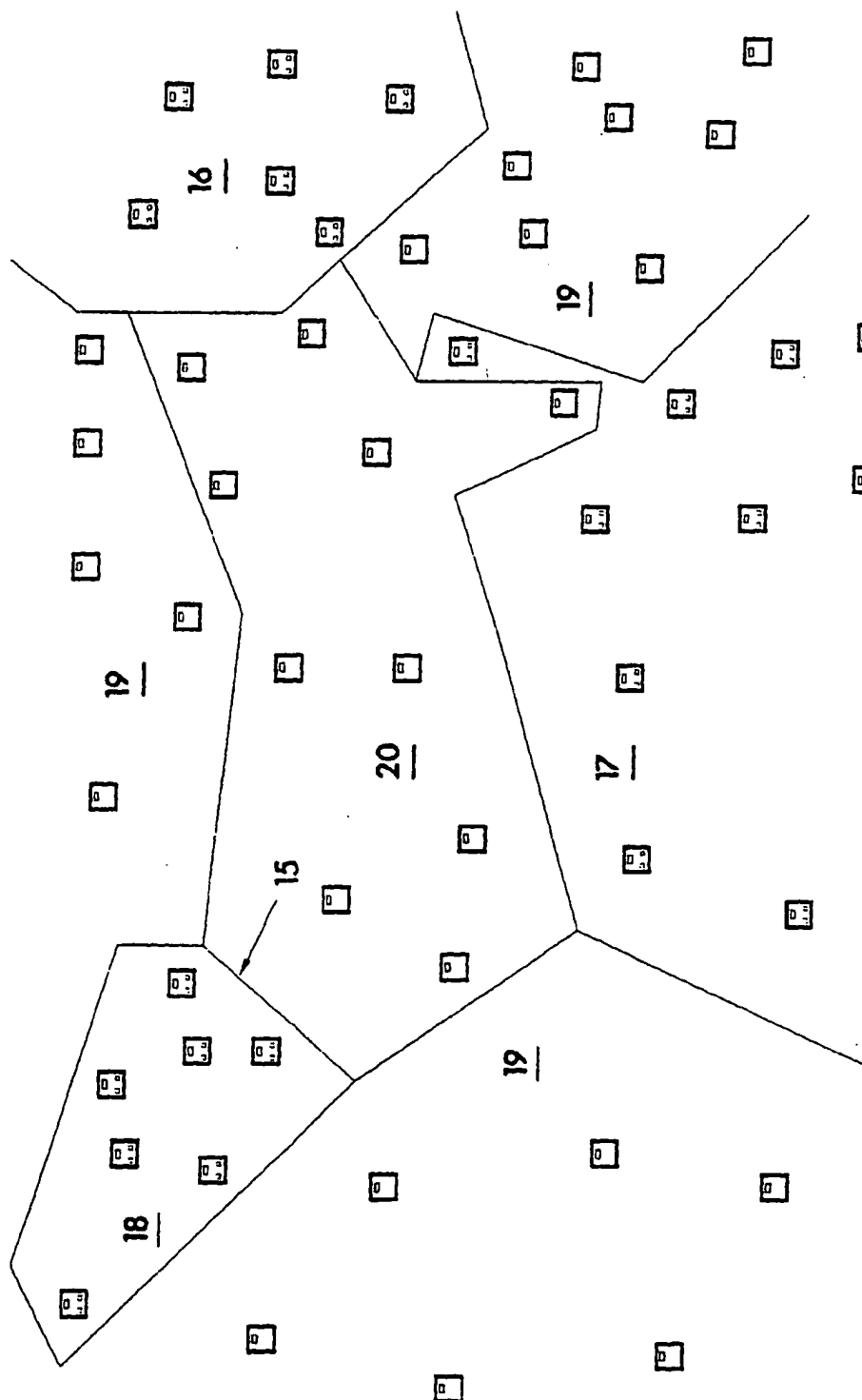


FIG. 2

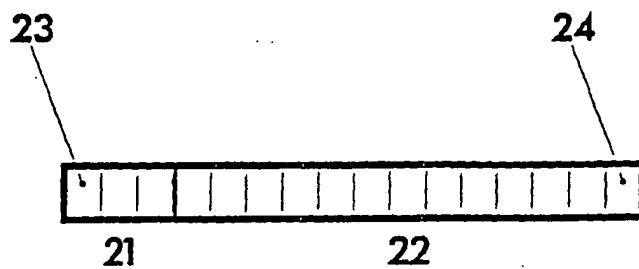


FIG. 3

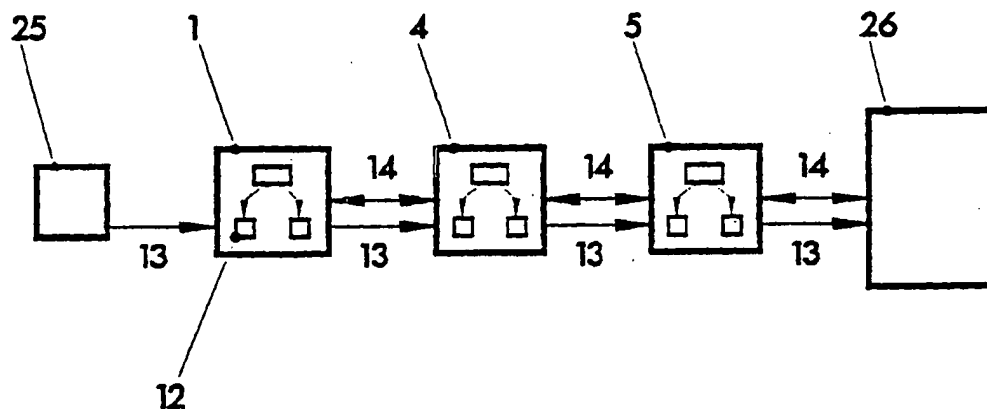


FIG. 4



# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/EP 93/03683

## A. CLASSIFICATION OF SUBJECT MATTER

H 04 L 12/56, H 04 Q 11/04

According to International Patent Classification (IPC) or to both national classification and IPC <sup>5</sup>

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H 04 L, H 04 Q, G 06 F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP, A2, 0 348 327 (INTERNATIONAL BUSINESS MACHINES) 27 December 1989 (27.12.89), abstract; column 1, line 4 - column 3, line 36; column 3, line 58 - column 6, line 40; fig. 1-4.	1, 6
A	EP, A1, 0 498 967 (BELL TELEPHONE) 19 August 1992 (19.08.92), abstract; page 2, lines 1-34; page 3, line 4 - page 6, line 30; fig. 1-13.	1, 4, 6-8
A	EP, A1, 0 276 754 (TELIC ALCATEL) 03 August 1988 (03.08.88),	1, 6

☐ Further documents are listed in the continuation of box C.

☐ Patent family members are listed in annex.

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Date of the actual completion of the international search  
11 August 1994

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## INTERNATIONAL SEARCH REPORT

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Application No

PCT/EP 93/03683

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	<p>EP, A2, 0 423 053 (INTERNATIONAL BUSINESS MACHINES) 17 April 1991 (17.04.91), abstract; column 1, line 1 - column 3, line 55. --</p>	1,6
A	<p>US, A, 4 905 233 (CAIN et al.) 27 February 1990 (27.02.90), abstract; column 4, line 12 - column 12, line 63; fig. 1-4B. --</p>	1,6
A	<p>US, A, 5 088 032 (BOSACK) 11 February 1992 (11.02.92), column 1, line 60 - column 3, line 2; column 2, line 32 - column 7, line 34; fig. 1-6. --</p>	1-6
A	<p>US, A, 5 067 127 (OCHIAI) 19 November 1991 (19.11.91), abstract; column 1, line 8 - column 3, line 5; column 9, line 27 - column 12, line 55; fig. 1,2,9-13. ----</p>	1-6

# ANHANG

zum internationalen Recherchen-  
bericht über die internationale  
Patentanmeldung Nr.

# ANNEX

to the International Search  
Report to the International Patent  
Application No.

# ANNEXE

au rapport de recherche inter-  
national relatif à la demande de brevet  
international n°

PCT/EP 93/03683 SAE 84019

In diesem Anhang sind die Mitglieder  
der Patentfamilien der im obenge-  
nannten internationalen Recherchenbericht  
angeführten Patentdokumente angegeben.  
Diese Angaben dienen nur zur Unter-  
richtung und erfolgen ohne Gewähr.

This Annex lists the patent family  
members relating to the patent documents  
cited in the above-mentioned inter-  
national search report. The Office is  
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La présente annexe indique les  
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relatifs aux documents de brevets cités  
dans le rapport de recherche inter-  
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